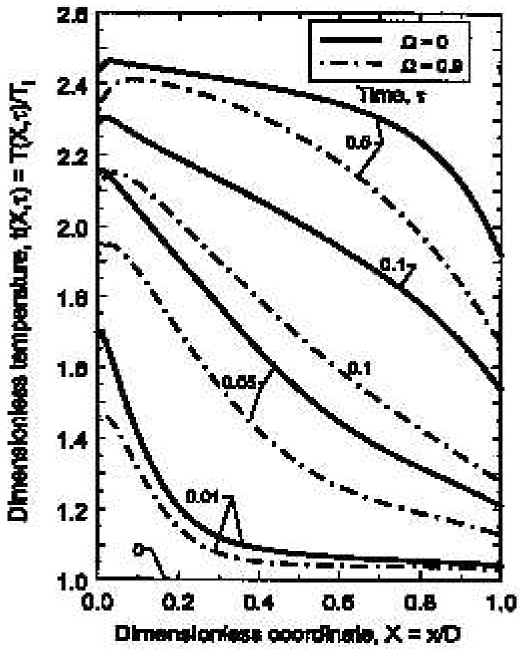
Transient Analysis Used to Study Thermal Radiation Effects in Single and Composite Semitransparent Layers

To withstand the high temperatures in advanced aircraft engines, some engine parts will need to be made of, or coated with, ceramic materials. However, radiant thermal energy can affect the performance of some ceramics because they are partially transparent in portions of the radiation spectrum. Infrared and visible radiation from hot surroundings, such as in a combustor, will penetrate into the material and heat it internally, similar to penetration and absorption of microwave energy when heating food in a microwave oven. Internal temperatures depend on radiative effects, heat conduction, and heat transfer at the material surfaces. Transient heating behavior is very important because radiant penetration provides more rapid internal heating than conduction alone, and thermal stresses during transients can be more severe than for steady conditions. Because temperatures in an engine are high, emission of radiation from within the hot ceramic material is also very important and must be included.

In a continuing in-house program at the NASA Lewis Research Center, analytical and numerical methods are being developed to apply radiative analysis to predict transient temperature distributions and heat flows in partially transmitting materials. Results have been obtained for a single plane layer, and a transient analysis is being developed for a two-layer composite where each layer has a different refractive index. Because the ceramic refractive indices are larger than one, internal reflections are produced at the surfaces and at the internal interface. As shown in reference 1, reflections tend to distribute energy within a layer, and this affects the transient temperature distributions.

Since the equations to calculate radiative transfer are rather complex integral equations, especially when internal scattering is included, it is important to develop approximate methods that can be conveniently incorporated into computer design programs. One approximate technique that has been shown to be useful and accurate for steady situations is the two-flux method. This method is formulated as simultaneous differential equations that, for transient situations, can be solved along with the transient energy equation in the material. The two-flux equations include scattering without increasing the difficulty in obtaining solutions. In reference 2 the two-flux equations were solved by a shooting method, and transient solutions were obtained for optical thicknesses of a plane layer up to 8. For optical thicknesses up to 50, a Green's function method was developed (ref. 3). Transient two-flux solutions were compared with exact numerical solutions of the radiative transfer equations from reference 4, and very good agreement was obtained. This method is currently being extended for a two-layer composite.



Two-flux transient temperatures in a layer, initially at uniform temperature, after exposure to radiative heating on one side and convective cooling on both sides.

The figure shows typical solutions obtained by the two-flux method for transient temperature distributions in a plane layer without scattering and with a scattering albedo of 0.9. The plane layer extends from $X= 0$ to 1, and the transient was initiated by suddenly supplying strong radiation to the boundary at $X = 0$, with the layer initially at a uniform temperature. (The layer's refractive index was 2.) The equations were solved in two spectral regions with optical thicknesses of 1 and 40 at high and low frequencies with approximately equal incident radiation in each frequency range. Energy was removed at both boundaries by convection. At the beginning of the transient, there was a rapid temperature increase and a large temperature gradient near $X = 0$ because of radiative heating. The temperatures were somewhat reduced when the scattering albedo was increased. Comparisons with results for an opaque layer showed that internal radiation has a large effect.

References

1. Siegel, R.: Refractive Index Effects on Transient Cooling of a Semitransparent Radiating Layer. J. Thermophys. Heat Transfer, vol. 9, no. 1, Jan.-Mar. 1995, pp. 55-62.

2. Siegel, R.: Two-Flux Method for Transient Radiative Heat Transfer in a Semitransparent Layer. Int. J. Heat Mass Transfer, to be published in 1996.

3. Siegel, R.: Two-Flux and Green's Function Method for Transient Heat Transfer in

a Semitransparent Layer. To be published in the Proceedings of the ICHMT International Symposium on Radiative Transfer, Kusadasi, Turkey, August 14-18, 1995.

4. Siegel, R.: Transient Heat Transfer in a Semitransparent Radiating Layer With Boundary Convection and Surface Reflections. Int. J. Heat Mass Transfer, vol. 39, no. 1, Jan. 1996, pp. 69-79.